

Solar Array and Auroral Charging Studies of DMSP Spacecraft

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The SSJ electrostatic analyzers and the SSIES plasma instruments on the DMSP spacecraft in low Earth polar orbit can be used to conduct case studies of auroral and solar array charging. We will use a program written in the Interactive Data Language (IDL) to evaluate questionable charging events in the SSJ records by comparing charging signatures in SSJ and SSIES data. In addition, we will assemble a number of case studies of solar array charging showing the signatures from the SSJ data and compare them to the SSIES charging signatures. In addition, we will use Satellite Tool Kit (STK) to propagate orbits, obtain solar intensity, and use to verify onset of charging with sunrise.

Nomenclature

<i>DMSP</i>	=	Defense Meteorological Space Program
<i>SSJ</i>	=	Precipitating Energetic Particle Spectrometer
<i>SSIES</i>	=	Special Sensor for Ions, Electrons and Scintillation
<i>IDL</i>	=	Interactive Data Language
<i>STK</i>	=	Satellite Tool Kit
<i>LEO</i>	=	Low Earth Orbit
<i>DOD</i>	=	Department of Defense
<i>GPS</i>	=	Global Positioning System
<i>NOAA</i>	=	National Oceanic and Atmospheric Administration
<i>SMC</i>	=	Air Force Space and Missile Systems Center (SMC)
<i>TLE</i>	=	Two-line Element Set
<i>NORAD</i>	=	North American Aerospace Defense Command

I. Introduction

The study of auroral and solar array charging is very important to the space physics community. This is because many people depend on a daily basis on satellite technology, such as GPS, that can be damaged in a charging event. We study these events by analyzing data collected by the SSJ and SSIES instruments on the DMSP satellites. The DMSP is a DOD program run by the SMC that designs, builds, launches, and maintains satellites which monitor meteorological, oceanographic, and solar-terrestrial physics environments. The SSJ/4 instrument measures the flux of charged particles as they enter the Earth's upper atmosphere from the near-Earth space environment. The SSIES instruments measures the ambient electron density and temperatures, the ambient ion density, and the average ion temperature and molecular weight at the DMSP orbital altitude. These measurements can be used to study charging events.

Spacecraft charging in LEO can be caused by the different factors. Some of those factors are change in density in the surrounding plasma, photo electron emission, secondary electrons and backscattered electrons and ions emission from energetic electron and ion collisions [Anderson, 2012]. Charging events occur when the satellites are in eclipse. These events are more likely to occur during the solar minimum when the plasma density in LEO is lower.

This project is focused on using the SSJ and SSIES data obtained from NOAA to study charging events. Our goal is to get a better understanding of the charging phenomena. This could help prevent future satellite damage

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caused by charging events since engineers would have more data available about the phenomena and could improve their building techniques to prevent spacecraft charging from happening.

II. Method

Surface charging is the result of a current balance on the surface of the spacecraft. Charging is described by the time dependent current balance relation,

$$\frac{dQ}{dt} = \frac{d\sigma}{dt} A = C \frac{dV}{dt} = \sum_k I_k \approx 0 \text{ (at equilibrium)}$$

where Q is the total charge and σ the surface charge density on the surface area A , C is the capacitance of the area A , and V the voltage of the surface. The currents of importance to the surface charging are: incident ions, incident electrons, backscattered electrons, conduction currents, secondary electrons, photoelectrons, and active currents sources (beams, thrusters).

There are certain conditions required for auroral charging. These conditions are [Gussenhoven et al., 1985]:

1. The satellite has to be in eclipse
2. There is an intense, energetic electron (> 14 keV population) precipitation event (Flux $> 10^8$ electrons $\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$)
3. There is a locally depleted ($< 10^4 \text{cm}^{-3}$) ambient plasma density

We also use certain criteria to identify charging events. These criteria are:

1. The event is least 3 seconds long
2. There is a voltage peak of at least -30 V
3. There is a distinguishable ion line and no underlying structure

The ion line represents an increase in the ion flux due to a change in the potential on the surface of the spacecraft. When the spacecraft gets negatively charged with respect to the plasma ambient, the ambient thermal ions are accelerated by the spacecraft potential as they pass through the aperture. Thus we observe a large flux in the ion energy channel corresponding to the spacecraft potential with respect to the ambient plasma [Anderson, 2012].

III. Analysis and Discussion

To read the data from the SSJ and SSIEs instruments, we used a program written in IDL. After reading the data we proceeded to plot the following: current density, ion and electron energy, ion and electron density, and latitude and longitude from the SSJ data; voltage, ion and electron density from the SSIES data. We also used STK to propagate the orbits of the satellites using TLE data sets obtained from NORAD. Once the orbits have been established, the STK solar illumination model was used to obtain solar intensity as a function of time and position along the spacecraft orbit track. Then we proceed to analyze the plots to identify possible charging events.

Figures 1 and 2 are the 24 hour plot of SSJ and SSIES data respectively. In the voltage plot from figure 2 we can see some abrupt changes in the voltage. These abrupt changes are considered possible charging events. If we take a smaller time interval of a possible charging event we can see more clearly the change in potential. This is shown in figure 3 where we have an interval of about two seconds. Figure 4 shows us the SSJ data plot for the same interval. In the ion energy plot we can clearly see an ion line corresponding to high ion density in that energy range. Finally using the STK data we can get solar intensity for this interval as shown in figure 5.

With the data collected we examined the possible charging event to confirm whether or not it is in fact a charging event. First we checked if the event complied with the conditions required for auroral charging. From figure 5 we see that the satellite is in eclipse since the solar intensity is zero for that period. In the electron energy plot from figure 4 we see an intense electron precipitation with population greater than 14 keV. Finally in the density plot from figure 3 we can see locally depleted ambient plasma. Since the event met all the requirements for auroral charging we can examine if it complies with the criteria to be confirmed as a charging event. We already know that the interval is at least 3 seconds long. There is at least a -30 V peak as we can see in the voltage plot from figure 3. From figure 4 we can clearly see a distinguishable ion line. After verifying the requirements and criteria we can confirm the event as a charging event.

The method used here to identify and confirm charging event is effective and relatively easy to use. With it we can study charging events more efficiently. This could lead to a better understanding of charging events which could be helpful for future improvement in the design methods of spacecraft.

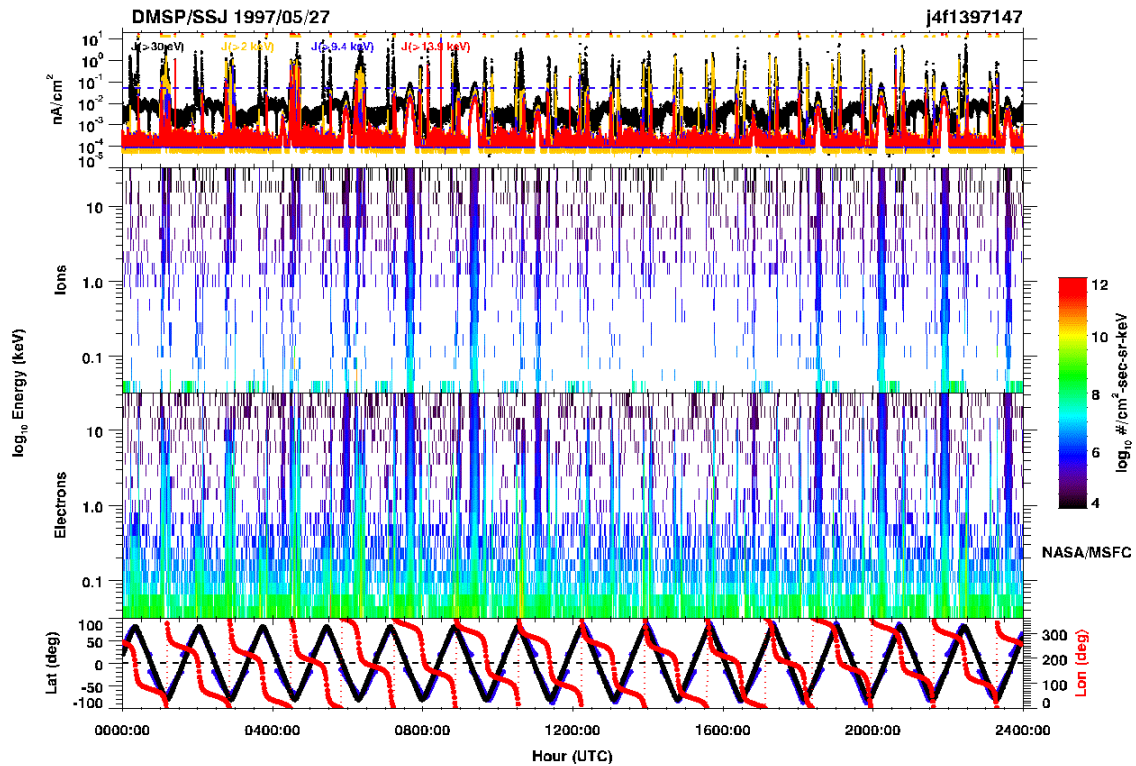


Figure 1. DMSP F13 SSJ data plot

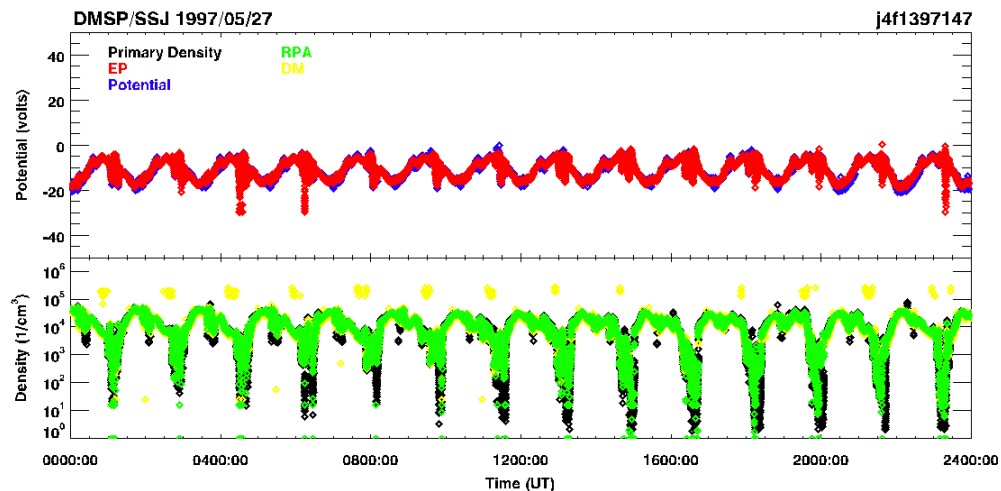


Figure 2. DMSP F13 SSIES data plot

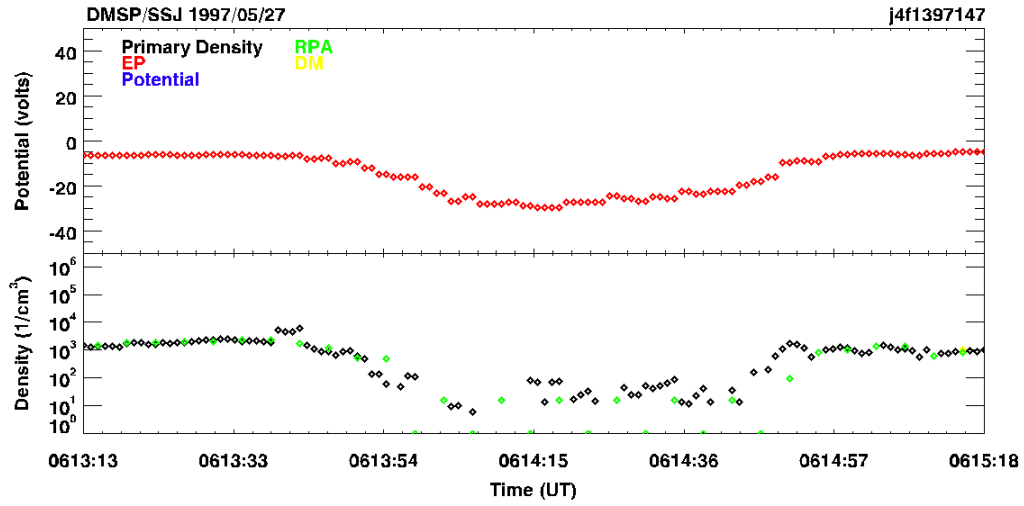


Figure 3. DMSP F13 Two minute interval SSIES plot

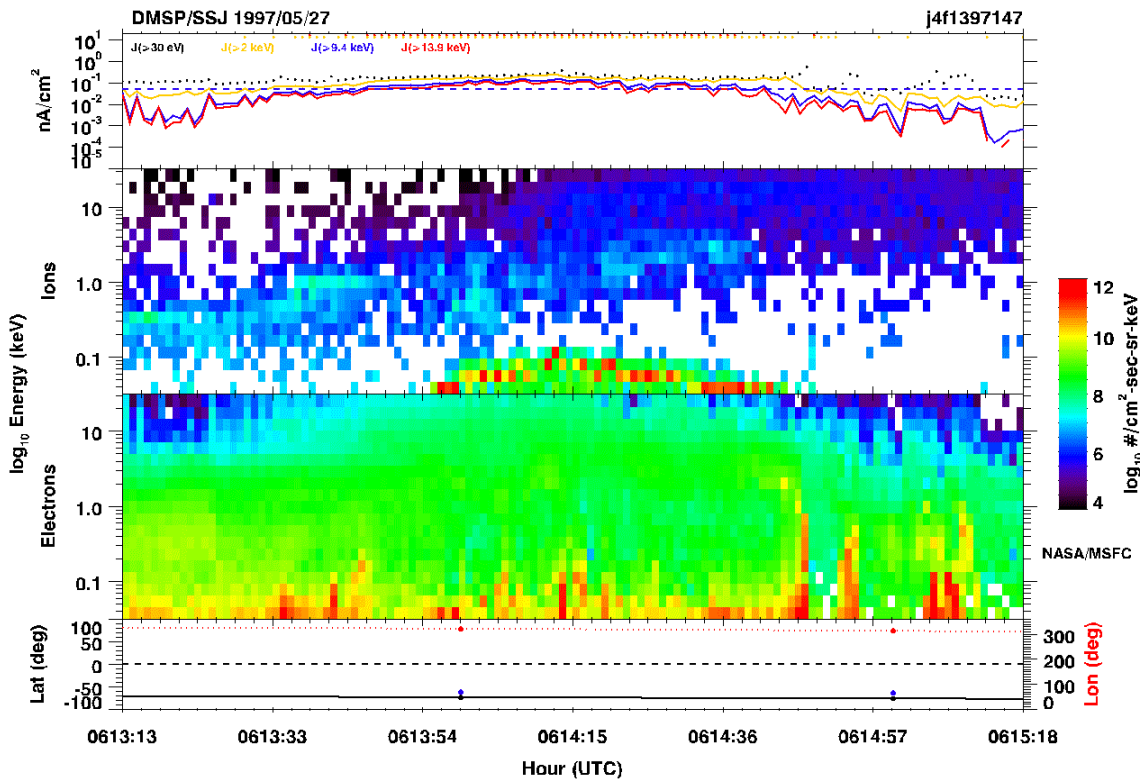


Figure 4. DMSP F13 Two minute interval SSJ plot

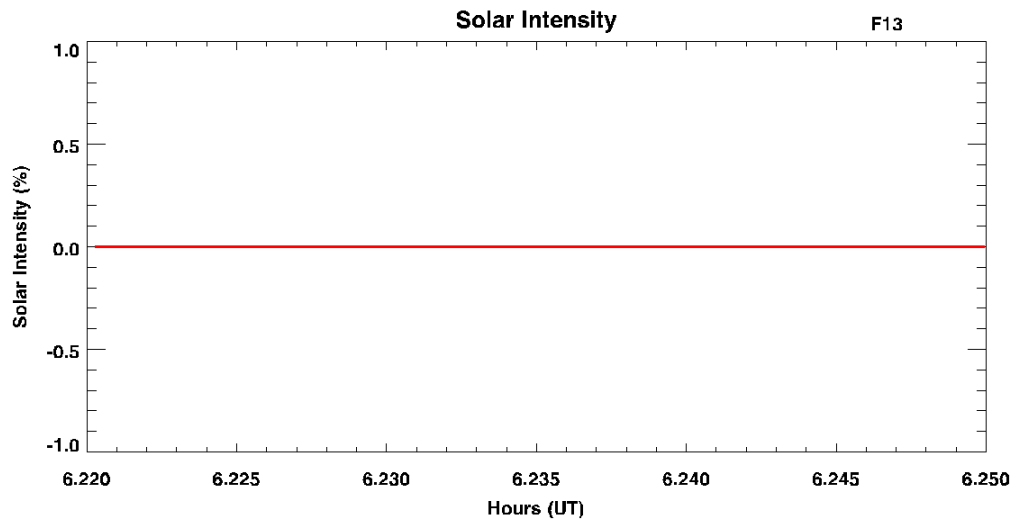


Figure 5. DMSP F13 Two minute solar intensity plot

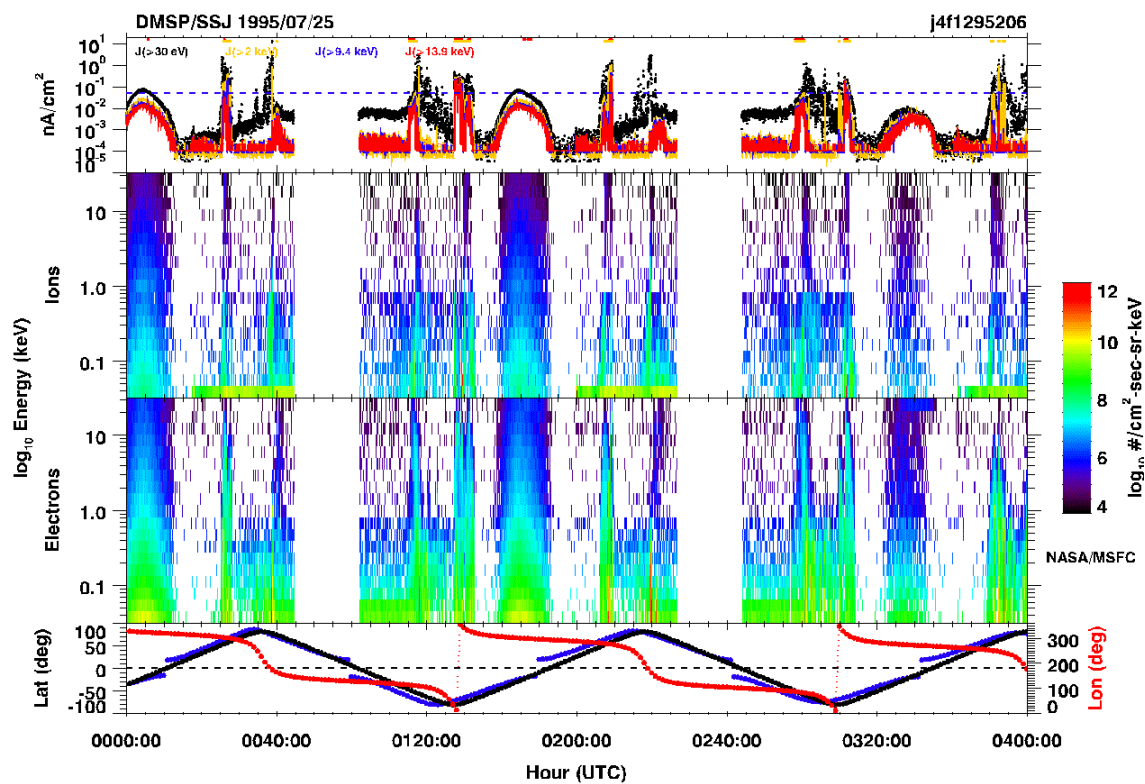


Figure 6. DMSP F12 Four hour SSJ plot

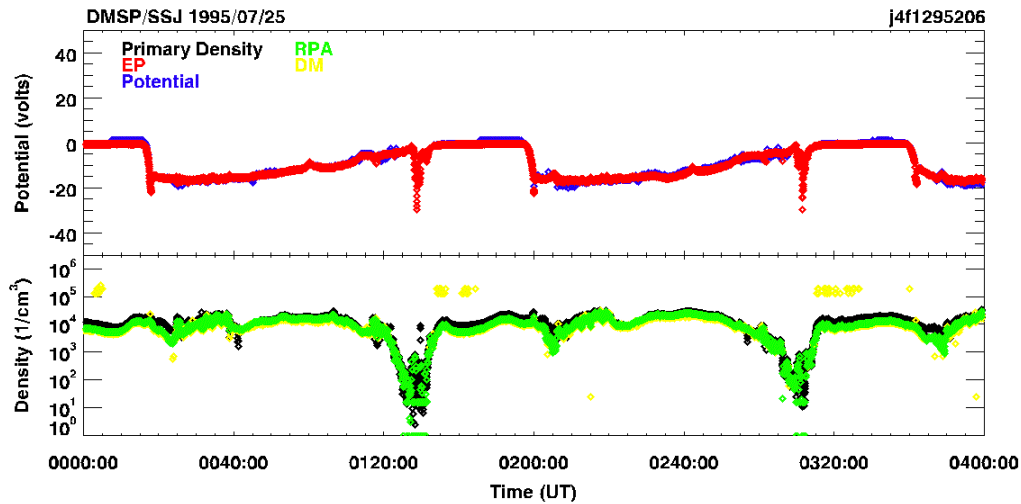


Figure 7. DMSP F12 Four hour SSIES plot

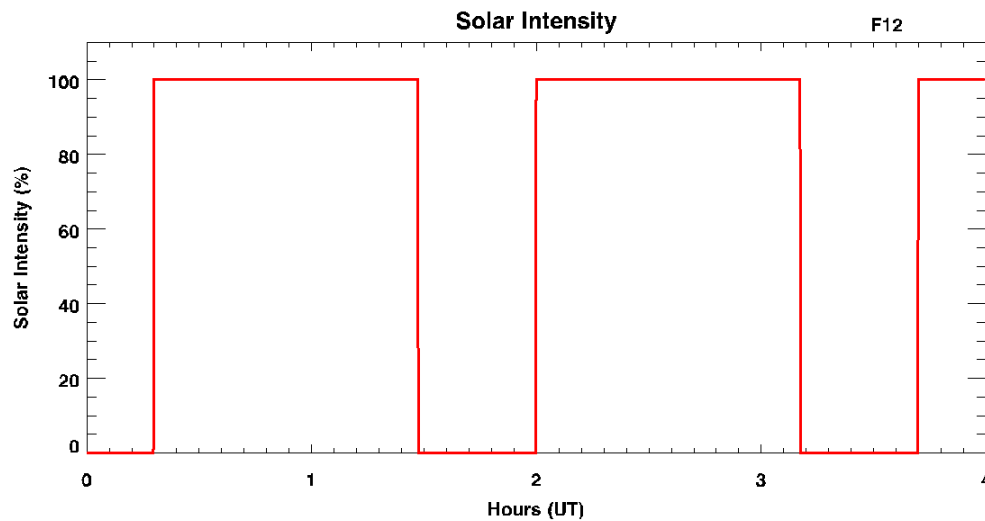


Figure 8. DMSP F12 Four hour solar intensity plot

After evaluating auroral charging events we studied solar array charging. Solar array charging, unlike auroral charging, occur while the satellite is in sunlight. This can be studied using figures 6, 7 and 8. We started by comparing the latitude/longitude plot from figure 6 with the solar intensity plot from figure 8. After comparing these two plots, we notice that the satellite is in sunlight while passing through the auroral zones. Then we looked at the ion energy/density plot on figure 6 and noticed that there is an increase in ion density in the low energy channel when the satellite goes through the auroral zone. These increases in ion density can be attributed to a solar array charging event. The increase in ion density happens because, as the spacecraft is moving through the auroral zone it gets negatively charged causing low energy ambient thermal ions to accelerated as they pass through the SSJ sensor aperture. That is the cause for the increase of the ion density in the low energy channel. This method has been used in a number of studies [e.g., DeForest, 1972; Mullen and Gussenhoven, 1982; Gussenhoven et al., 1985; Frooninckx and Sojka, 1992; Wahlund et al., 1999; Anderson, 2012]. We noticed that the increased density does not persist through the entire period the spacecraft is illuminated. One explanation for this could be that since the data being examined is from the summer in the northern hemisphere, we only see solar array charging while the satellite passes by the auroral zone of the northern hemisphere because the solar intensity there is much higher than the auroral zone on the southern hemisphere for this period of the year.

Another example of solar array charging can be seen in figures 9, 10 and 11. In this case we also have the satellite in sunlight while it passes by the auroral zones. In this case we only see an increase in ion density only in about half of the orbit (on ascending node). One explanation for this could be that the satellite is on descending node it is moving away from the sunlight. Thus the ion flux is lower because the sensor is facing the opposite direction of the movement of the spacecraft which implies a lower flux than when the sensor is facing the direction of motion of the spacecraft.

Although these charging events are not as significant as the ones previously analyzed, they still play an important role in the understanding of the spacecraft charging phenomena. To get a full understanding of spacecraft charging it is necessary to examine this phenomenon in detail from every possible angle.

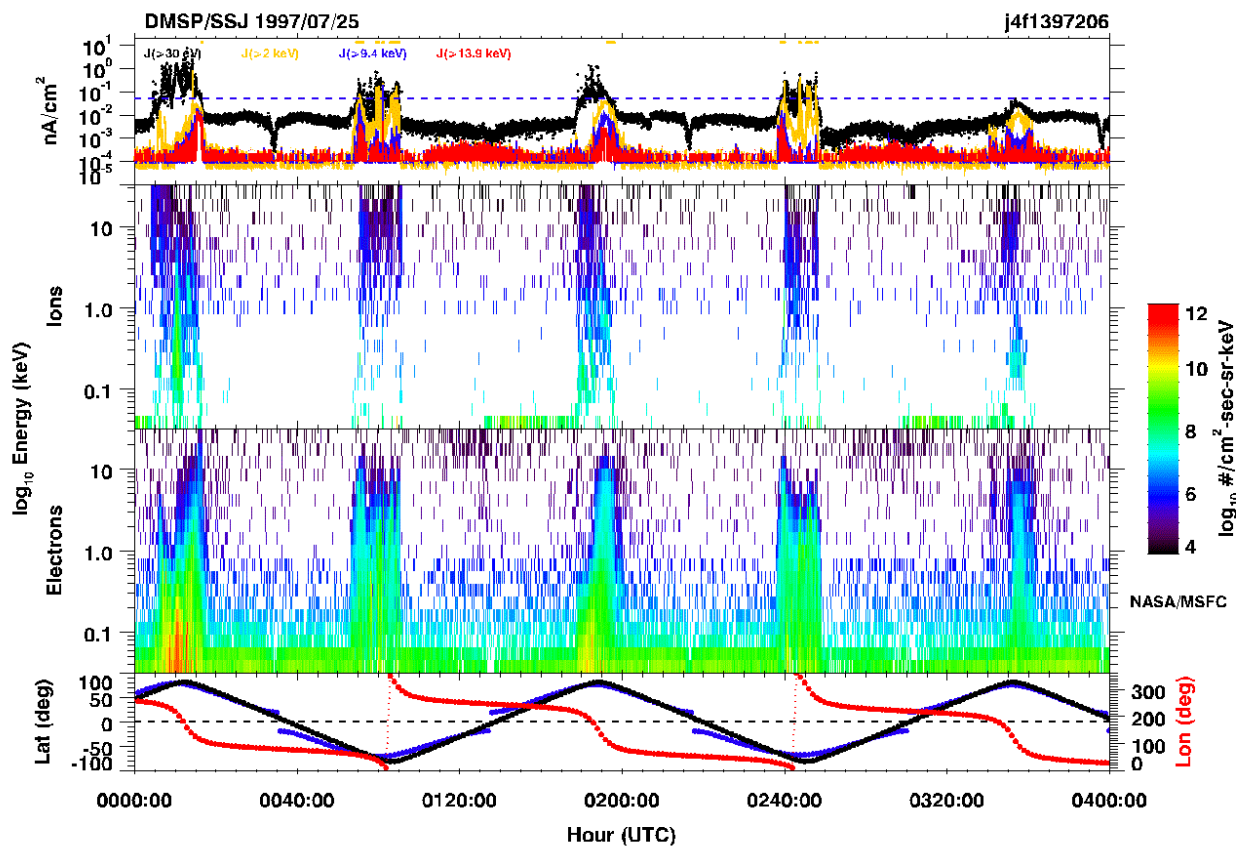


Figure 9. DMSP F13 Four hour SSJ data plot

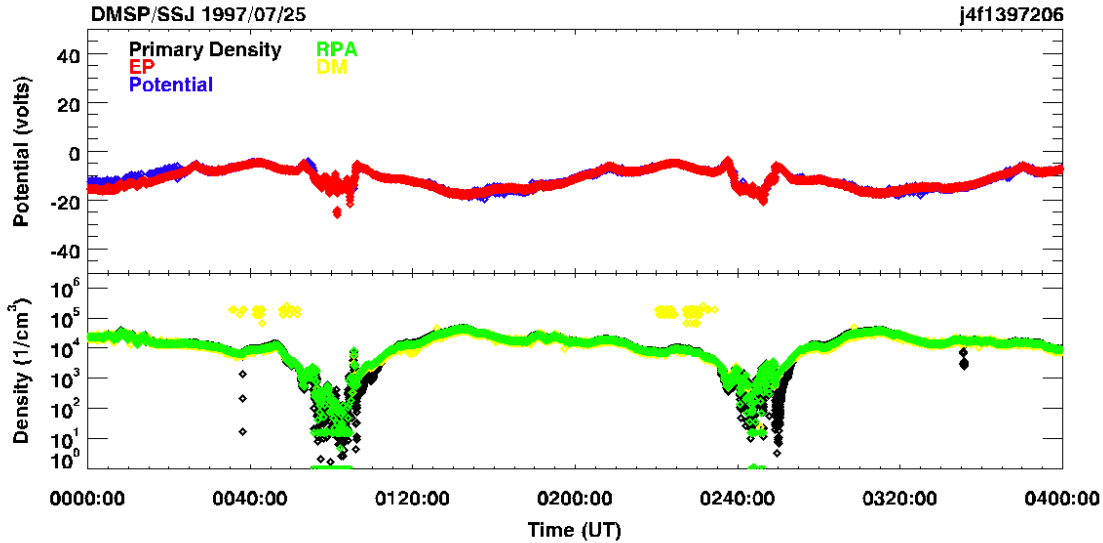


Figure 10. DMSP F13 Four hour SSIES data plot

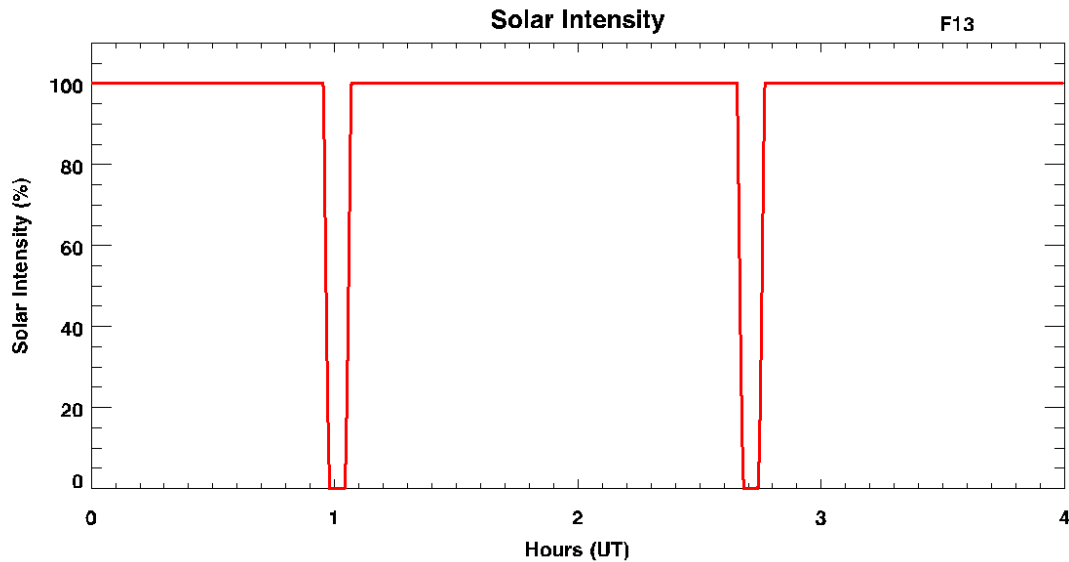


Figure 11. DMSP F13 Four hour solar intensity plot

IV. Future Work

There are some improvements that can be done to the SSJ/SSIES IDL program to make it more efficient. When looking at the data sets I noticed that some sets had missing files meaning that we can't do a full analysis of the charging events. One of the improvements would be to tell the user when the data sets are not complete and give him/her the option to choose another date. Another improvement would be to include an option where the user can choose a satellite and change dates without having to input the satellite each time a different date is chosen. This way the user can focus on just working on one satellite at a time. Using this program it could also be possible to create a routine that could examine the entire database available to identify possible charging events.

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